OPTIMIZING TECHNIQUES FOR TIME MINIMIZING TRANSSHIPMENT PROBLEM AND ITS VARIANT

A Synopsis

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1. Introduction

Optimization plays an important role in everyone's life related to expenditure and profit. Whenever dealing with expenditure we always try to minimize it and for profit we always try to maximize it. The transportation of goods and/or services (from the plants/warehouse to the consumer/final destination) is a major concern for every manufacturer. These problems can be seen mathematically with the help of following definitions:

Transportation Programming Problem (Classical transportation problem):

The classical transportation problem (TP) is a well- structured problem that deals with the distribution of goods from m suppliers (also known as origin; say $O_i : i = 1,2, \dots m$) to n customers (also known as destinations; say $D_j : j = 1,2, \dots n$). Each of these suppliers can ship to any of the customers (or purchaser) at a per unit shipping cost c_{ij} (i.e. from supplier O_i to customer D_j). Each supplier has a_i units of capacity and each purchaser has a requirement of b_j units. The objective is to determine the number of units x_{ij} to be transported from source O_i to destination D_j so that the total transportation cost is minimized. In addition, the supply limits at the source and the demand requirements at the destination must be satisfied exactly.

Mathematical symbols used in transportation table are shown in the following table 1.

Table 1

	D_1	D_2	…	D_j	…	D_n	$supply$
O_1	$x_{11}[c_{11}]$	$x_{12}[c_{12}]$	…	$x_{1j}[c_{1j}]$	…	$x_{1n}[c_{1n}]$	a_1
O_2	$x_{21}[c_{21}]$	$x_{22}[c_{22}]$	…	$x_{2j}[c_{2j}]$	…	$x_{2n}[c_{2n}]$	a_2
⋮	⋮	⋮	⋱	⋮	⋱	⋮	⋮
O_i	$x_{i1}[c_{i1}]$	$x_{i2}[c_{i2}]$	…	$x_{ij}[c_{ij}]$	…	$x_{in}[c_{in}]$	a_i
⋮	⋮	⋮	⋱	⋮	⋱	⋮	⋮
O_m	$x_{m1}[c_{m1}]$	$x_{m2}[c_{m2}]$	…	$x_{mj}\,[c_{mj}]$	…	$x_{mn}\,[c_{mn}]$	a_m
$demand$	b_1	b_2	…	b_j	…	b_n	

Then the Mathematical model of transportation problem is to find x_{ij} which

$$Minimize\ Z = \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}x_{ij}$$

Subject to

$$\sum_{j=1}^{n} x_{ij} = a_i \qquad i = 1,2,\dots m$$

$$\sum_{i=1}^{m} x_{ij} = b_j \qquad j = 1,2,\dots n$$

$$x_{ij} \geq 0 \quad for\ all\ \ i = 1,2,\dots m\ ;\ j = 1,2,\dots n;$$

a_i and b_j are non negative numbers.

A transportation problem is called balanced transportation problem if

$$\sum_{i=1}^{m} a_i = \sum_{j=1}^{n} b_j \qquad (i.e. total\ supply = total\ demand\ )$$

Otherwise it is unbalanced transportation problem. Unbalanced transportation problem can be converted to balanced transportation problem by introducing a dummy row or a dummy column.

Note: *TP is a linear programming problem with* $m \times n$ *variables and* $m + n$ *constraints.*

Time minimizing transportation problem with mixed constraints:

In classical transportation problem all supply and destinations have fixed amount of goods. Practically, the problems having such restrictions will not be always possible. Different sources and destinations impose different restrictions on supply and demand respectively according to their availability and requirement. Some sources want to supply exactly the fixed amount of goods, but some other sources do not want to supply the amount less than a fixed amount. This case arises for the big factories, companies etc. Rest other sources are not able to supply more than a fixed amount of goods. This case arises for small factories, companies etc. Similar conditions occur for the destinations also. Due to the sources and destinations having mixed nature, the problem is said to be a transportation problem with mixed constraints. In real life, most of the problems are related to mixed constraints having many applications in industry, planning, communication network, scheduling, transportation and allotment etc.

In many situations people feel that time is more important than money. So, it is also important that the time required for transportation should also be minimized. The time minimizing transportation problem (TMTP) is to find the amount of a uniform (homogeneous) commodity transported from a source (i.e. factory where the commodity is manufactured) to the respective destination (i.e. warehouse where the commodity is to be distributed) satisfying the given supply

and demand limits so that the total transportation should be completed in minimum time. This problem actually minimizes the maximum of transportation time t_{ij} needed between a supply point and a demand point such that the distribution between the two points is positive.

The mathematical model for time minimizing transportation problem with mixed constraints (TMTP-MC) is to find $t_{ij}\ and\ x_{ij}$ which

$$Minimize\ Z = \max_{i,j}\{t_{ij} : x_{ij} > 0\}$$

Subject to

$$\sum_{j=1}^{n} x_{ij} \leq a_i\ , \qquad \forall i \in V_1$$

$$\sum_{j=1}^{n} x_{ij} \geq a_i\ , \qquad \forall i \in V_2$$

$$\sum_{j=1}^{n} x_{ij} = a_i\ , \qquad \forall i \in V_3$$

$$\sum_{i=1}^{m} x_{ij} \leq b_j\ , \qquad \forall j \in U_1$$

$$\sum_{i=1}^{m} x_{ij} \geq b_j, \qquad \forall j \in U_2$$

$$\sum_{i=1}^{m} x_{ij} = b_j, \qquad \forall j \in U_3$$

$$x_{ij} \geq 0\ ; i = 1,2..m\ and\ j = 1,2, \dots n,$$

$$a_i \geq 0\ ; i = 1,2 \dots m\ and\ b_j \geq 0\ ; j = 1,2 \dots n$$

Where V_1, V_2, V_3 are pair wise disjoint subsets of $\{1,2, \dots m\}$ such that $V_1 \cup V_2 \cup V_3 = \{1,2, \dots m\}$ and U_1, U_2, U_3 are pair wise disjoint subsets of $\{1,2, \dots n\}$ such that $U_1 \cup U_2 \cup U_3 =$

$\{1,2,\ldots n\}$ .If V_1, V_2, U_1 and U_2 are empty then the problem becomes the time minimizing transportation problem with equality constraints.

It is assumed that

- The carriers have sufficient capacity to carry goods from an origin to a destination in a single trip.
- They start simultaneously from their respective origin.

Classical transshipment problem.

In classical transportation problem shipment of homogeneous commodity takes place from source to destination such as from factories to warehouses, or from warehouses to supermarkets. But instead of direct shipments from sources to destinations, the commodity can be transported to a particular destination through one or more intermediate source and destination. Each of these points in turn supply to other points. Thus when the shipments pass from destination to destination and from source to source also, then minimizing the overall transshipment cost satisfying the demand and supply limits of sources and destinations is said to be a transshipment problem or a classical transshipment problem. In the transshipment problem all the sources and destinations can function in any direction including from destination to destination, source to source, source to destination, destination to source also. In many applications shipments are allowed between supply points or between demand points to reduce the total transporting cost. Usually, in the absence of the transshipment, the transportation cost goes higher. Hence the transshipment is also very useful to reduce the transportation cost.

Suppose we have *m* origins and *n* destinations. Since in a transshipment problem, any origin or destination can ship to any other origin or destination, it is convenient to number them

successively so that the origins are numbered from $O_i : i = 1,2, \dots m$ and the destination from $D_j : j = m+1, m+2, \dots m+n$. In transshipment problem each supply and demand point is called as node point. Let x_{ij} $(i, j = 1,2, \dots m+n, j \neq i)$ be the quantities shipped from node point i *to* node point j and c_{ij} be the unit cost of shipping from node point i to node point j.

The total amount shipped from an origin must be equal to the amount it produces plus what it transships. Similarly, the total amount received at a destination must be equal to its demand plus what it transships. Thus the transshipment problem may be expressed as:

$$Minimize\ Z = \sum_{i=1}^{m+n} \sum_{j=1}^{m+n} c_{ij} x_{ij}$$

Subject to

$$\sum_{j=1, j\neq i}^{m+n} x_{ij} - \sum_{j=1, j\neq i}^{m+n} x_{ji} = a_i\ , \qquad i = 1,2, \dots m$$

$$\sum_{i=1, i\neq j}^{m+n} x_{ij} - \sum_{i=1, i\neq j}^{m+n} x_{ji} = b_j,\ \ j = m+1, m+2, \dots m+n$$

$$x_{ij} \geq 0\ ; i, j = 1,2, \dots m+n, i \neq j$$

$$a_i \geq 0\ ; i = 1,2 \dots m\ and\ b_j \geq 0\ ; j = m+1, m+2 \dots m+n$$

The above formulation represents a Linear Programming Problem (LPP) with $(m+n)^2$ variables and $m+n$ constraints. The problem is similar to transportation problem but not exactly since the coefficients of x_{ji} are -1.

In transshipment problem the cost for transporting a product from i^{th} node point to j^{th} node point need not be equal to the cost for transporting a product from j^{th} node point to i^{th} node point.

Transshipment table

	O_1	O_2	…	O_i	…	O_m	D_{m+1}	D_{m+2}	…	D_{m+j}	…	D_{m+n}	$supply$
O_1	x_{11}	x_{12}	…	x_{1i}	…	x_{1m}	$x_{1,m+1}$	$x_{1,m+2}$	…	$x_{1,m+j}$	…	$x_{1,m+n}$	a_1
O_2	x_{21}	x_{22}	…	x_{2i}	…	x_{2m}	$x_{2,m+1}$	$x_{2,m+2}$	…	$x_{2,m+j}$	…	$x_{2,m+n}$	a_2
⋮	⋮	⋮	⋱	⋮	⋱	⋮	⋮	⋮	⋱	⋮	⋱	⋮	⋮
O_i	x_{i1}	x_{i2}	…	x_{ii}	…	x_{im}	$x_{i,m+1}$	$x_{i,m+2}$	…	$x_{i,m+j}$	…	$x_{i,m+n}$	a_i
⋮	⋮	⋮	⋱	⋮	⋱	⋮	⋮	⋮	⋱	⋮	⋱	⋮	⋮
O_m	$x_{m,1}$	$x_{m,2}$	…	$x_{m,i}$	…	$x_{m,m}$	$x_{m,m+1}$	$x_{m,m+2}$	…	$x_{m,m+j}$	…	$x_{m,m+n}$	a_m
D_{m+1}	$x_{m+1,1}$	$x_{m+1,2}$	…	$x_{m+1,i}$	…	$x_{m+1,m}$	$x_{m+1,m+1}$	$x_{m+1,m+2}$	…	$x_{m+1,m+j}$	…	$x_{m+1,m+n}$	−
D_{m+2}	$x_{m+2,1}$	$x_{m+2,2}$	…	$x_{m+2,i}$	…	$x_{m+2,m}$	$x_{m+2,m+1}$	$x_{m+2,m+2}$	…	$x_{m+2,m+j}$	…	$x_{m+2,m+n}$	−
⋮	⋮	⋮	⋱	⋮	⋱	⋮	⋮	⋮	⋱	⋮	⋱	⋮	⋮
D_{m+j}	$x_{m+j,1}$	$x_{m+j,2}$	…	$x_{m+j,i}$	…	$x_{m+j,m}$	$x_{m+j,m+1}$	$x_{m+j,m+2}$	…	$x_{m+j,m+j}$	…	$x_{m+j,m+n}$	−
⋮	⋮	⋮	⋱	⋮	⋱	⋮	⋮	⋮	⋱	⋮	⋱	⋮	⋱
D_{m+n}	$x_{m+n,1}$	$x_{m+n,2}$	…	$x_{m+n,i}$	…	$x_{m+n,m}$	$x_{m+n,m+1}$	$x_{m+n,m+2}$	…	$x_{m+n,m+j}$	…	$x_{m+n,m+n}$	−
$demand$	−	−	−	−	−	−	b_{m+1}	b_{m+2}	…	b_{m+j}	…	b_{m+n}	−

2. Mathematical formulation for time minimizing transshipment problem and its variants

Mathematical model for time minimizing transshipment problem (TMTs-EC):

In time minimizing transshipment problem we have to find t_{ij} and x_{ij} which

(P1) $$Minimize\ Z = \max_{i,j}\{t_{ij} : x_{ij} > 0\}$$

Subject to

$$\sum_{j=1, j\neq i}^{m+n} x_{ij} - \sum_{j=1, j\neq i}^{m+n} x_{ji} = a_i\ , \qquad i = 1,2, \dots m$$

$$\sum_{i=1, i\neq j}^{m+n} x_{ij} - \sum_{i=1, i\neq j}^{m+n} x_{ji} = b_j,\ \ j = m+1, m+2, \dots m+n$$

$$x_{ij} \geq 0\ ; i, j = 1,2, \dots m+n, i \neq j$$

$$a_i \geq 0\ ; i = 1,2 \dots m\ and\ b_j \geq 0\ ; j = m+1, m+2 \dots m+n$$

where, each symbol has their usual meaning as explained earlier.

Unbalanced transshipment problem arises when

$$\sum_{i=1}^{m} a_i \neq \sum_{j=m+1}^{m+n} b_j$$

It is assumed in the proposed problem that

(i) The carriers have sufficient capacity to carry goods from an origin to a destination in a single trip

(ii) They start simultaneously from their respective origins.

Mathematical model for variant in time minimizing transshipment problem (Time minimizing transshipment problem with mixed constraints/TMTsP-MC):

In the classical transshipment problem availabilities at the sources and the requirements at the destinations are fixed quantities and met exactly by the solution. In transshipment problem with mixed constraints (TMTsP-MC) the availability and / or requirement constraints were inequations which opposed to the usual equations. That is, availability constraints and requirement constraints are of mixed type. The problem having such type of constraints is said to be the transshipment problem with mixed constraints.

In time minimizing transshipment problem with mixed constraints we have to find $t_{ij}$and x_{ij} which

(P2) $$Minimize\ Z = \max_{i,j}\{t_{ij}: x_{ij} > 0\}$$

Subject to

$$\sum_{j=1,j\neq i}^{m+n} x_{ij} - \sum_{j=1,j\neq i}^{m+n} x_{ji} \leq a_i\ , \forall i \in V_1$$

$$\sum_{j=1,j\neq i}^{m+n} x_{ij} - \sum_{j=1,j\neq i}^{m+n} x_{ji} \geq a_i\ , \forall i \in V_2$$

$$\sum_{j=1,j\neq i}^{m+n} x_{ij} - \sum_{j=1,j\neq i}^{m+n} x_{ji} = a_i\ , \forall i \in V_3$$

$$\sum_{i=1,i\neq j}^{m+n} x_{ij} - \sum_{i=1,i\neq j}^{m+n} x_{ji} \leq b_j\ , \forall j \in U_1$$

$$\sum_{i=1,i\neq j}^{m+n} x_{ij} - \sum_{i=1,i\neq j}^{m+n} x_{ji} \geq b_j, \forall j \in U_2$$

$$\sum_{i=1,i\neq j}^{m+n} x_{ij} - \sum_{i=1,i\neq j}^{m+n} x_{ji} = b_j, \forall j \in U_3$$

$$x_{ij} \geq 0\ ; i, j = 1,2, \ldots m+n, i \neq j$$

$$t_{ii} = 0, i = 1,2, \ldots m + n$$

$$a_i \geq 0 \; ; i = 1,2 \ldots m \; and \; b_j \geq 0 \; ; j = m + 1, m + 2 \ldots m + n$$

where V_1, V_2, V_3 are pair wise disjoint subsets of $\{1,2, \ldots m\}$ such that $V_1 \cup V_2 \cup V_3 = \{1,2, \ldots m\}$ and U_1, U_2, U_3 are pair wise disjoint subsets of $\{m + 1, m + 2, \ldots m + n\}$ such that $U_1 \cup U_2 \cup U_3 = \{m + 1, m + 2, \ldots m + n\}$ .If V_1, V_2, U_1 and U_2 are empty then the problem becomes the time minimizing transshipment problem with equality constraints (TMTsP-EC).

3. Applications of Time Minimizing Transshipment Problem

The Time Minimizing transshipment problem has a great importance from practical standpoint and encountered in such situations:

(i). **Transshipment of perishable goods**- In the transportation of perishable food items such as fresh fruit, vegetables, milk, etc. duration of delivery is highly essential. As any time lag in transportation may result in much larger loss than any cost advantage attained by transporting it at lower cost.

(ii). **Transshipment of military equipment**: - In military transportation, at the time of emergency, military armaments or weapons are required to be delivered from their military bases to battlefronts, where time of transportation is of prime consideration.

(iii). **Transshipment of emergency relief goods**: - At the time when natural calamities like earth quake, floods, tsunami, etc. strike emergency relief goods are required to be transported in minimum time. As a brief delay may cause massive loss of lives.

(iv). **Transshipment of medical supplies**: - In hospital, transportation of ambulances, medicines, blood (or blood products) and other medical supplies are need to be timely delivered.

4. Survey of Published Research

Literature search revealed that much effort has been concentrated on classical cost minimizing transportation problem without transshipment and classical time minimizing transportation problem without transshipment. Only two papers are devoted to time minimizing transportation problem with transshipment.

Garg and Prakash (1985) [4] developed a two- phase computational method to obtain the solution of time minimizing transshipment problem with equality constraints. In the first phase, a set of identical problem, each having the objective to find minimal time route from an origin to a destination through intermediate points consisting of origins or destinations, are solved. In the second phase, a standard time minimizing transportation is solved. The durations of transportation for this problem of the second phase are the minimal durations of transportation from origins to destinations provided by the solutions of the problems of the first phase. The desired solution to the problem under consideration is provided by the solutions of the problems considered in two phases.

Khurana and Verma (2015) [6] considered a transshipment problem keeping in mind the objective to minimize the duration of transportation. They have developed a method to solve the original transshipment problem by transforming into an equivalent transportation problem and the optimal solution of the original problem is obtain from the optimal solution of the transformed transportation problems.

Agarwal and Sharma (2018) [3] developed a method ‘Swap-in Swap-out’ for time minimizing transportation with mixed constraints. The model of time minimizing transportation

problem with mixed constraints is converted to standard linear programming type model by introducing additional variables in the form of slack and artificial variables (excluding surplus variables). These additional variables contribute to make an identity matrix as an initial basis matrix for the better start. The basic steps taken in this method are swap -in a non- basic variable and swap-out a basic variable at each iteration to improve the solution. Such an improvement is continued till the optimality is reached. An algorithm has been developed for the method and illustrated through numerical evidence.

Agarwal and Sharma (2014) [1] have developed an open loop method to determine an optimal shipment time of time minimizing transportation problem with mixed constraints. The method starts from a basic feasible solution and moving towards an optimal solution. In this process, a basic cell with highest shipment time is vacated by shifting the assigned amount to a cell having less time. The path of this shifting is detected through an open loop, which initiates with the greatest time basic cell and terminate at the cell having lower time. This process terminates, if no such open loops are possible. An algorithm has been developed for the proposed method. This algorithm converges in a finite number of steps and its efficiency is demonstrated through a numerical example.

Recently, Agrawal and Sharma 2018[2] have developed a shootout method to determine an optimal transportation time in time minimizing transportation problem with mixed constraints by avoiding the cells associated with greatest time for allocation. In the path of getting the minimum time of transportation, cells are avoided one by one in decreasing sells are allocated to find the optimal solution. The greatest time of positive allocated cells gives the optimal time. A shoot out algorithm has been developed and it is demonstrated with some numerical illustration.

The problem of minimizing the duration of transportation in the transshipment problem with mixed constraints has not yet been dealt and this itself is the motivating force for the study of TMTsP with mixed constraints.

5. Proposed Work

In literature, much effort has been concentrated on time minimizing transportation problem but the problem of minimizing the duration of transportation with transshipment has been dealt only by Garg and Prakash (1985)[4], Khurana and Verma (2015)[6] .These papers searched the possibility of further reducing the optimal time in time minimizing transportation problem with equality constraints by permitting the transshipment.

We are motivated to study the extension of time minimizing transportation problem with equality constraints to permit transshipment with the additional feature that shipment may go via any sequence of points rather than being restricted to direct connections from one source to one of the destinations.

We propose some directions along which optimization methods/algorithms can be developed for problems TMTsP-EC (P1) and TMTsP-MC (P2). A method developed by Khurana and Verma (2015) [6] assigns the cells of transportation table sustaining feasibility to get a basic feasible solution and then improving it through a number of iterations to achieve optimal solution. It takes too much time and iterations to get the optimal solution. We are motivated towards not to start with initial basic feasible solution of the proposed problem but to avoid the cells with greatest time in decreasing order one by one in the transshipment table as long as the problem sustains feasibility. Then assignment in the remaining cells will be done by any method of getting basic feasible solution of cost minimizing transportation problem. It is

hoped that the greatest time of the assigned cells will be the optimal time of the proposed problem (P1**)**.

A Swap-in Swap-out method for time minimizing transportation with mixed constraints has been developed by Agarwal and Sharma (2018)[3]. In this method, after getting a basic feasible solution, a basic variable is exchanged with a non- basic variable to achieve optimal solution. We are hopeful of developing a swap-in swap-out type method for the proposed problem on the basis of performing matrix operations.

An open loop method is developed by Agarwal and Sharma (2014) [1] for getting an optimal solution of time minimizing transportation problem with mixed constraints. In this method an initial basic feasible solution is obtained and then it is improved by exchanging a basic cell of greatest time with a basic/non-basic cell with lesser time than that, by connecting them through an open loop. A method is to be developed by exchanging the basic cells with decreasing order of time one by one connecting them with a non-basic cell associated with lesser time till the feasibility of the problem sustains.

A Shoot out method may be developed for the proposed problem by removing basic cells with greatest time one by one in transshipment table as long as feasibility sustains on the pattern of the paper 'Shoot out Method for Time Minimizing Transportation Problem with Mixed Constraints by Agarwal and Sharma (2018)[2]. There after remaining cells will be assigned.

We will also try to study the variant of transshipment problem with equality constraints by relaxing the equality restriction on transshipment constraints into $\geq/\leq/=$ type of constraints. A method will be developed for getting an optimal solution for this type of variant in transshipment problem (P2).

All the proposed methods will be presented in the form of respective algorithms and the algorithms will be illustrated with the help of numerical examples also.

Comparative study will be made among all the proposed methods, with their limitations, advantages/disadvantages. These methods would also be compared with the currently existing methods of Garg and Prakash (1985), Khurana and Verma (2015) for time minimizing transshipment problem.

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